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The art of coupon tests

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ABSTRACT

Tensile coupon tests are commonly carried out to determine the material properties of metallic materials in research and industry. However, ambiguities are found in the current specifications in determining initial Young's modulus of material, which may lead to different test results. The material properties lay the crucial foundation in research and structural design. Different researchers may interpret coupon test results differently. Therefore, standard procedures of coupon test and the interpretation of test results are important and worth investigating. In this study, a series of tensile coupon tests on metallic materials, such as cold-formed carbon steel, cold-formed stainless steel and aluminum alloy, were carried out using different test and data analysis procedures. Two types of stainless steel materials, namely lean duplex and ferritic, were investigated. The test and data analysis procedures of loading rate on coupon specimens, determination of cross-sectional area of curved coupons and Young's modulus were carefully designed. In this study, tensile coupon test and data analysis procedures are proposed for both flat and curved coupons. The proposed procedures are able to eliminate possible errors and provide clear guidelines for tensile coupon tests.

1. Introduction

Metallic materials are commonly used in structural projects, due to the high strength-to-weight ratio, high degree of recyclability and ease of construction comparing with other constructional materials. Determination of material properties for metallic materials, especially the initial Young's Modulus, yield strength, ultimate strength and strains, lays a solid foundation in structural design and research. Therefore, tensile coupon tests as the most commonly used experimental method to obtain material properties are widely known and frequently carried out by engineers and researchers. Specifications on tensile testing method for metallic materials are also available to facilitate engineers and researchers to obtain material properties. However, it should be noted that inconsistent coupon test procedure and data analysis leads to inaccurate results. Therefore, it is worth investigating tensile coupon tests in order to propose a standard and user-friendly procedure for test and data interpretation.

Previous investigations [1–6] have found that stress increases with loading rate for various metallic materials, and thus determination of yield strength and ultimate strength is sensitive to the loading rate during testing. The Australian Standard (AS) [7], European Code (BSI) [8] and American Specification (ASTM) [9] specify a range of loading rate for tensile coupon tests. However, the lower bound and upper bound of the loading rate provide quite different results in terms of the yield strength and ultimate strength. Krempl and Khan [5] indicated that the stress drops and maintains at the equilibrium boundary (static curve) by holding the strain for a very long time during testing, and the static stress–strain curve can be obtained under a vanishing loading rate. However, it is not practical to hold the strain for such a long time or use a vanishing loading rate. In addition, it is also observed by Krempl and Khan [5] that the stress drops diminishing with time. Therefore, coupon tests were conducted by holding the strain for 1–2 min during testing for the purpose of obtaining the static stress–strain curves [10–12]. The Guide to Stability Design Criteria for Metal Structures [13] suggested to hold the strain for at most 5 min, so as to eliminate the effect of loading rate and obtain static material properties. Therefore, coupon test procedure and loading rate are ambiguous, which may lead to an inconsistent test result.

Curved coupon specimens obtained from corners of cold-formed sections were conducted by many researchers [10,14–16] to investigate the strength enhancement due to cold-forming process. However, it is difficult to measure the cross-sectional area accurately or apply uniform tensile stress to coupon specimen during testing, because of the curved geometry of the specimen. Current specifications [7–9,17] provide limited guidance to determine the cross-sectional area of curved coupons. Therefore, researchers [10,14–16] used different methods for coupon tests on curved specimens, which may lead to different test results.

The initial Young's modulus is considered as one of the most important material properties. It also affects the accuracy in determining the 0.2% proof stress ($\sigma_{0.2}$). However, the current specifications [7–9,17] recommended different methods to obtain the Young's modulus. It is expected that different values of initial Young's modulus are obtained using different methods, which may eventually influence the coupon test results. Thus, there is an eminent need to compare these methods

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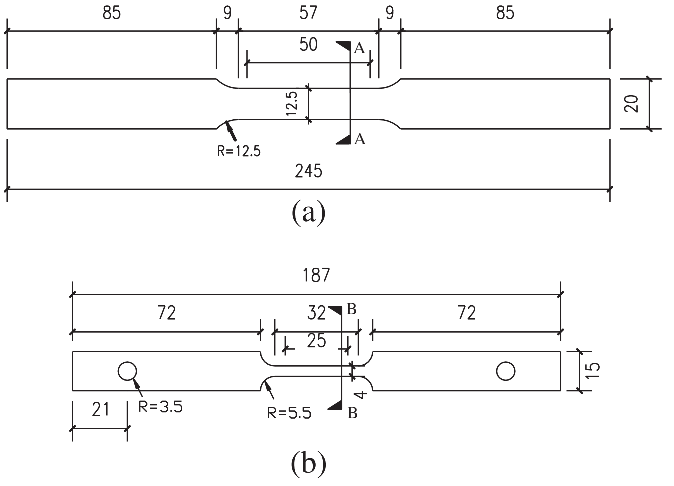

Fig. 1. Dimension of coupon specimens. (a) Dimension of flat coupon. (b) Dimension of curved coupon.

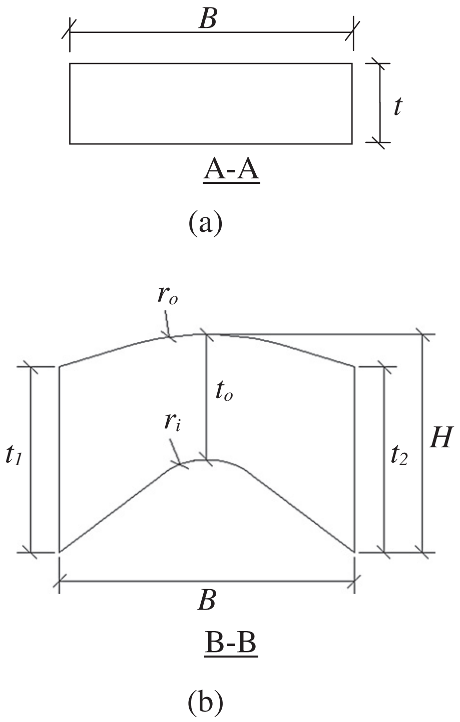

Fig. 2. Definition of symbols for the coupon specimens. (a) Definition for symbols of cross-sectional dimensions in flat coupon specimens. (b) Definition for symbols of cross-sectional dimensions in curved coupon specimens.

in terms of accuracy and simplicity, and recommend clear guidelines for tensile coupon tests.

In this study, tensile coupon tests using different test and data analysis procedures were conducted. The procedures of coupon tests were carefully designed. The test specimens in this study include cold-formed carbon steel grade G450, cold-formed lean duplex stainless steel (EN 1.4162), cold-formed ferritic stainless steel (EN 1.4003) and aluminum T6 alloy. The cold-formed carbon steel and aluminum alloy are widely used in construction, while cold-formed lean duplex stainless steel is a relatively new material that is gaining popularity in construction industry. A relatively convenient procedure for tensile coupon tests is recommended.

2. Experimental investigation

2.1. Test specimens

A total of 48 tensile coupon tests of cold-formed carbon steel (G450), cold-formed lean duplex stainless steel (EN 1.4162), cold-formed ferritic stainless steel (EN 1.4003) and aluminum T6 alloy was carried out. The cross-sectional dimensions of the flat and curved coupon specimens were measured. The nominal dimensions of the coupon specimens are shown in Fig. 1. The cross-sectional dimensions of the curved coupon specimens are summarized in Table 1 with the definition of symbols shown in Fig. 2. The coupon specimens are labeled such that the material, shape of the coupon and the loading rate could be identified, as shown in Tables 1 and 2. The first letter represents the metallic material. The letters G, L, F and A represent cold-formed steel G450, lean duplex stainless steel, ferritic stainless steel and aluminum alloy, respectively. The second letter indicates the shape of the coupon, such as “F” and “C” representing flat and curved coupons, respectively. The letter right after the hyphen represents the loading rate applied on the specimen during testing. There are four series of loading rate, namely slow (S), research (R), lower-bound (L) and upper-bound (U), representing the slow loading rate, the loading rate recommended for research purpose, the lower-bound and upper-bound of loading rates recommended by the ASTM specification [9], respectively. The loading rates for each series and material are summarized in Table 2 and detailed in Section 2.3 of this paper. Two or three coupon tests were carried out for each series, and thus the loading rates in Table 2 are the average value measured from the coupon tests in each series. The number shown in the specimen label after the loading rate series represents the number of tests in each series, as shown in Tables 3–6. For example, the specimen “AF-R2” represents the aluminum alloy (A) flat coupon (F) tested under the loading rate recommended for research purpose (R) for the second coupon test. The zinc coating on coupon surfaces of the cold-formed carbon steel was removed using hydrochloric acid prior to measuring the cross-sectional dimensions, except for specimens GF-R1-zinc, GF-R2-zinc and GF-R3-zinc with the coating remain throughout the test for comparison purpose. The MTS tensile loading machine of 50 kN capacity was used for the tensile coupon tests, except that the specimens LF-R1-Instron and LF-R1-MTS250 were tested using tensile loading machines of Instron 50 kN capacity and MTS 250 kN capacity, respectively.

The flat coupon specimens of cold-formed steel G450 (G) were extracted from steel sheet, while the curved coupon specimens GC-R1 and GC-R2 were extracted from the two corners of a cold-formed steel channel section with nominal cross-sectional dimension ($D \times B \times t$) of $136 \times 52 \times 1.9$ mm, where D is the depth of the web, B is the width of

Table 1
Dimension of curved coupon specimens.

Curved specimen	t_o	t_1	t_2	B	H	r_i	r_o	A_w	A_c	A_g
	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm^2)	(mm^2)	(mm^2)
GC-R1	1.78	2.50	2.64	3.89	3.04	1.00	3.25	8.50	8.35	8.37
GC-R2	1.67	2.49	2.49	3.94	2.92	1.00	3.75	8.05	8.02	8.10
LC-R1	2.93	3.38	3.51	3.80	4.07	1.25	3.60	13.67	12.06	12.08
LC-R2	2.93	3.65	3.90	3.96	4.13	0.50	3.25	12.69	13.22	13.47